Brodric Young

ECEN 350

Op-Amp Gain Lab

ECEN 350 – Op-Amp Gain Lab (60 points)

(jas, Op-Amp Gain Lab.docx, 12/28/2024)

Note: You can work in pairs if desired on this lab, although no three person teams are allowed. Submit an electronic version of a lab report to receive credit for doing this lab. The goal of your **lab report is to provide sufficient documentation so that the lab can be repeated if necessary**. Therefore, simply add to this document to arrive at your lab report, as all of the explanatory text, procedures, and Discussion and Conclusion questions contained in this document are required for a complete lab report. So, for your lab report, **add a cover page that includes name or names, class and name of the lab. Also add in your results, and answers to the Discussion and Conclusions questions to the existing lab document**. While you are to share all **Procedure** items with your lab partner if you worked in a pair, your **Discussion and Conclusions** section is to be uniquely yours and not a copy of your lab partners. See the grading rubric at the end of this document for more details.

Purpose: To analyze and construct a voltage follower, inverting and non-inverting operational amplifier circuits to better understand the utility of op-amps.

Parts and Equipment:

- 1 – LF356 Op-amp
- 1 – 0.1 μF Capacitor
- 1 – 100 Ω resistor
- 1 – 1.0 kΩ resistors
- 1 – 2.0 kΩ resistor
- 1 – 10 kΩ resistor
- 1 – 18 kΩ resistor
- 1 - 10 MΩ Resistor
- 1 – Portable Digital Multimeter (DMM)
- 1 - VirtualBench Measurement System and Computer.
- 2 - 1X/10X Probes for the VirtualBench MSO.
- 1 – BNC to alligator or micro-grabber cable for VirtualBench FGEN output.
- 1 - Breadboard.

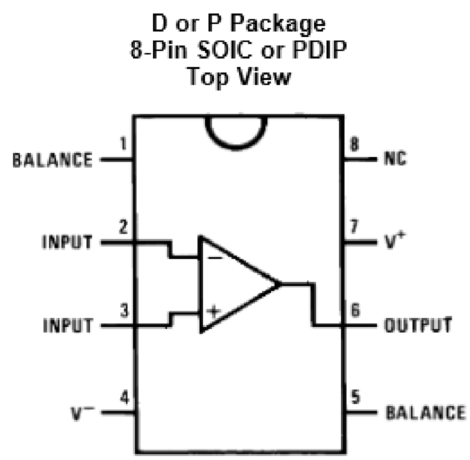


Figure 1: Pin-out for LF356 Op-Amp.

Procedure:

Part 1 – Voltage Follower Application.

On rare occasions when breadboarding op-amps and other integrated circuits in Dual In-Line packages (DIPs), not all leads make good electrical contact with the metal connectors underneath the rows in the breadboard. Consequently, when debugging a breadboarded op-amp circuit it is recommended to check continuity between the pins of the DIP and the corresponding rows in the breadboard.

1. Connect up the voltage follower configuration illustrated below in **Figure 2**. The Thevenin equivalent circuit in **Figure 2** providing the input voltage to the voltage follower was previously used in the DMM Measurement Details Lab and Oscilloscope Lab to emphasize the difficulty of accurate voltage measurements in a circuit having a large Thevenin resistance. The LF356 op-amp configured as a voltage follower provides an effective means to alleviate this measurement problem. In this application the LF356 op-amp configured as a voltage follower is referred to as a buffer amplifier.

   Use the VirtualBench adjustable +25 V supply set to 10.0 V for the V_{cc} supply and the adjustable -25 V supply set to -10.0 V for the V_{ee} supply. Use the VirtualBench adjustable +6 V supply set to 5.0 V for the V_{th} supply. Include a 0.1 µF decoupling capacitor C1 connected between adjacent V_{ee} and ground connection strips.

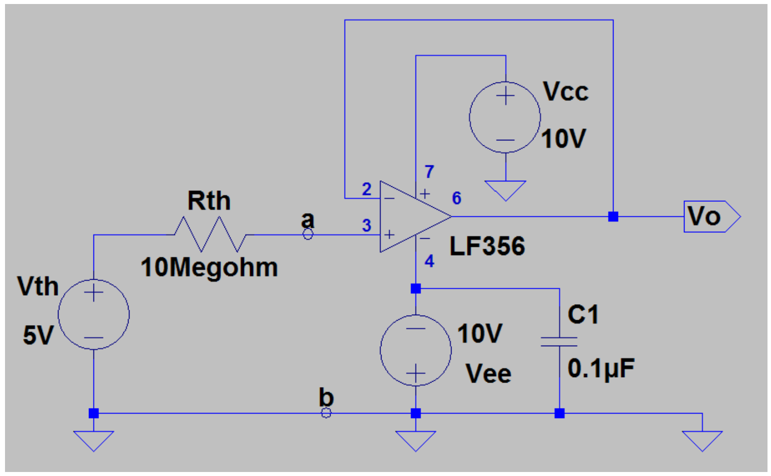


Figure 2: Voltage Follower Configuration.

2. Configure the VirtualBench DMM to measure DC voltage on the 10 V input range and portable DMM to measure DC voltage on the 20 V input range. (Note: Both DMMs have a default input impedance of 10 MΩ when measuring DC voltages.)
3. Referring to **Figure 2**, connect the VirtualBench DMM to measure the voltage between the a and b terminals, and the portable DMM to measure the voltage from V_O to ground.
4. Record the resulting measured voltage below including units.

V_{ab}_Meas = __2.56V______. (2 points.)

V_O_Meas_1 = __2.45V_____. (2 points.)

5. Next disconnect the VirtualBench DMM from the a and b terminals illustrated in **Figure 2**, and record the resulting output voltage, including units, measured by the Portable DMM. (Note: Your V_O_Meas_2 voltage value in step 5 should be approximately two times larger than your V_O_Meas_1 voltage value from step 4, else there is a set-up problem.)

V_O_Meas_2 = __4.99V____. (2 points.)

6. Turn off the VirtualBench Power Supplies and remove the adjustable +6 V supply from the circuit, to be replaced with the VirtualBench FGEN output for part 2.

Part 2 – Non-Inverting Amplifier Configuration.

1. Connect up the non-inverting amplifier configuration illustrated in **Figure 3**. Resistor R3 is included simply to help protect the plus (+) input of the LF356 from possible static discharges when connecting and removing FGEN and oscilloscope leads on the V_i input. R3 has no influence on the voltage gain or input impedance of this non-inverting amplifier.

Use the VirtualBench adjustable +25 V supply set to 10.0 V for the V_{cc} supply and the adjustable -25 V supply set to -10.0 V for the V_{ee} supply. Again, include a 0.1 μF decoupling capacitor C1 connected between adjacent V_{ee} and ground connection strips.

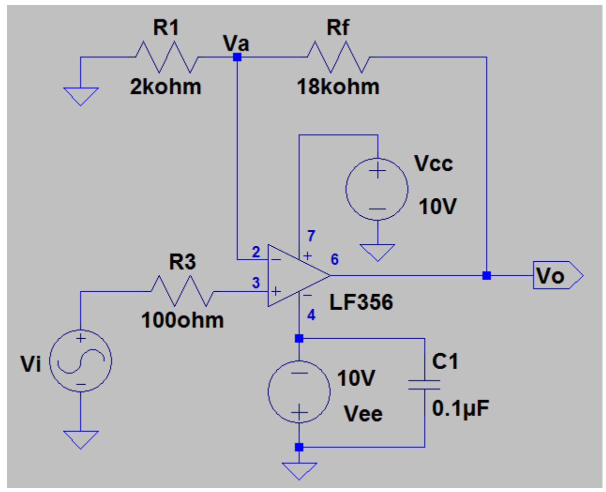


Figure 3: Non-Inverting Amplifier Configuration to be Characterized.

2. Connect the oscilloscope probe with the red marking bands to Channel 1 (CH 1) and the oscilloscope probe with the yellow marking bands to Channel 2 (CH 2) on the VirtualBench CH 1 and CH 2 oscilloscope BNC connectors. Make sure the slide switches at the probe tip end of the oscilloscope probes are set to 10X versus 1X.
3. Make sure that both the CH 1 and CH 2 are set for AC coupling and 10X probe attenuation.
4. Set the VirtualBench Function Generator to output a 250 mV peak-to-peak sine wave with zero DC offset voltage, and connect the BNC to alligator or micro-grabber cable so as to provide the voltage V_i input indicated in **Figure 3**.
5. Connect up oscilloscope, with CH 1 to monitor V_o and oscilloscope CH 2 to monitor V_i for the **Figure 3** circuit, with the larger V_o signal as the oscilloscope trigger source.
6. Using the VirtualBench built-in oscilloscope waveform measurements, add a **Peak-to-Peak** Waveform Measurement to CH 1.
7. The oscilloscope's automatic **peak-to-peak** measurement function does not work well on relatively small signals because of noise, and so use the waveform cursors instead to measure the CH 2 peak-to-peak voltage V_i. To do so set the cursor type as **Voltage** and position the two waveform cursors to provide a voltage difference, i.e., ΔY, that represents the average peak-to-peak voltage of the signal at V_i in **Figure 3**. Record this cursor measured peak-to-peak value as V_i (pk-pk) in **Table 1** below, adjusting the cursors as necessary for the different input frequencies. Also, for each input frequency

listed in **Table 1** below, record the CH 1 **Peak-to-Peak** Waveform Measurement as V_o (pk-pk) in the table.

8. Complete **Table 1** below with measured and calculated values for each of the input frequencies listed, adjusting the frequency of the FGEN output accordingly. Be sure to include units for V_i and V_o, either by adding them once to each column label at the top or to each measured value. While the voltage ratio V_o/V_i is dimensionless, the dB magnitude is defined as follows $|\mathbf{A_v}|_{dB} = 20\log_{10}(|V_o/V_i|)$. (8 points total.)

Table 1: Measured Data for the Non-Inverting Amplifier Configuration.

Input Frequency	V_i (pk-pk)	V_o (pk-pk)	$\|Av\| = \|V_o/V_i\|$	$\|\mathbf{A_v}\|_{dB}$[1]
10 Hz	0.250V	2.45V	9.8	19.8dB
100 Hz	0.255V	2.50V	9.8	19.8dB
1 kHz	0.251V	2.52V	10.1	20.1dB
10 kHz	0.247V	2.49V	10.1	20.1dB
30 kHz	0.247V	2.49V	10.1	20.1dB
100 kHz	0.247V	2.42V	9.8	19.8dB
300 kHz	0.243V	2.07V	8.5	18.6dB
1 MHz	0.243V	1.07V	4.4	12.9dB

1 – Voltage Gain Magnitude $|\mathbf{A_v}|_{dB} = 20\log_{10}(|V_o/V_i|)$.

11. Based on your **Table 1** data, plot the magnitude in dB on the vertical axis versus frequency on the horizontal axis, using a logarithmic scale for the frequency, which is a Bode magnitude plot. The MATLAB **semilogx**() plot command can be used to provide the logarithmic frequency axis scale if you choose to use MATLAB. Include appropriate horizontal and vertical axis labels with units along with the title “Gain Magnitude versus Frequency of A Non-Inverting Op-Amp Configuration – Your Name or Names”. Replace the plot below with your version, keeping the figure number and caption. (6 points.)

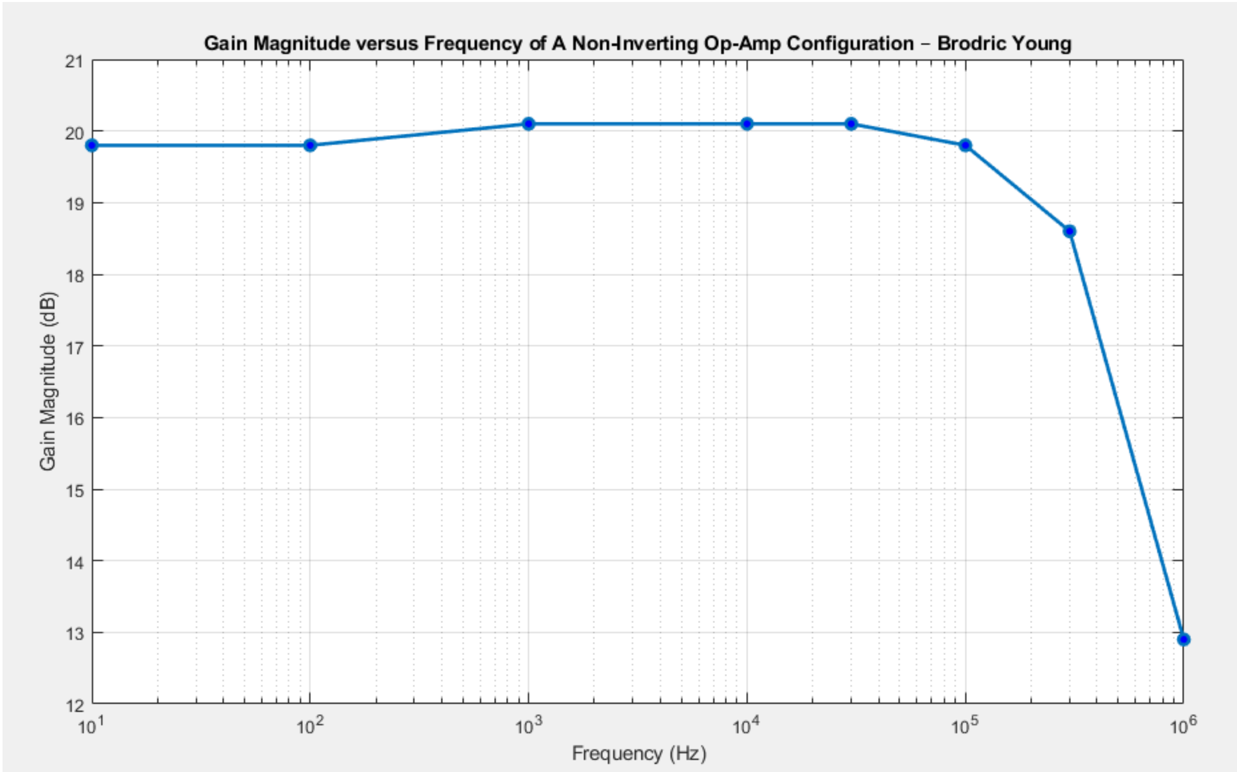


Figure 4: Frequency Response of the Non-Inverting Op-Amp Configuration of **Figure 3**.

Part 3 – Inverting Amplifier Configuration

1. Connect up the inverting amplifier configuration illustrated in **Figure 5**.

Use the VirtualBench adjustable +25 V supply set to 10.0 V for the V_{CC} supply and the adjustable -25 V supply set to -10.0 V for the V_{ee} supply. These supplies share a common ground with the adjustable +25 V supply output voltage being ≥ 0 V and the adjustable -25 V supply output voltage being ≤ 0 V. The negative supply has switching noise on it that can be problematic for higher speed op-amps, like the LF356. Consequently, a 0.1 μF decoupling capacitor C1, as shown in **Figure 5**, is to be included to help shunt the switching noise from V_{ee} to ground. A pair of the long power supply rail connection strips available on breadboards is recommended for V_{ee} and ground for this lab, with decoupling capacitor C1 connected between adjacent connection strips.

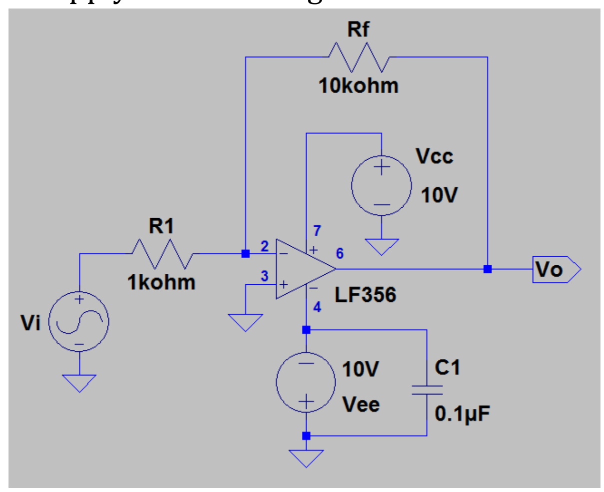


Figure 5: Inverting Amplifier Configuration to be Characterized.

2. Connect the oscilloscope probe with the red marking bands to Channel 1 (CH 1) and the oscilloscope probe with the yellow marking bands to Channel 2 (CH 2) on the VirtualBench CH 1 and CH 2 oscilloscope BNC connectors. Make sure the slide switches at the probe tip end of the oscilloscope probes are set to 10X versus 1X.
3. Start up the VirtualBench user interface software and for the CH 1 and CH 2 settings  make sure that both are set for AC coupling and 10X probe attenuation.
4. Set the VirtualBench Function Generator to output a 250 mV peak-to-peak sine wave with zero DC offset voltage, and connect the BNC to alligator or micro-grabber cable so as to provide the voltage V_i input indicated in **Figure 5**.
7. Connect up two channels on the oscilloscope, with CH 1 to monitor V_o and CH 2 to monitor V_i for the **Figure 5** circuit, with the larger V_o signal as the oscilloscope trigger source.
5. Using the VirtualBench built-in oscilloscope waveform measurements, add a **Peak-to-Peak** Waveform Measurement to CH 1.
6. The oscilloscope's automatic **peak-to-peak** measurement function does not work well on relatively small signals because of noise, and so use the waveform cursors instead to measure the CH 2 peak-to-peak voltage V_i. To do so set the cursor type as **Voltage** and position the two waveform cursors to provide a voltage difference, i.e., ΔY, that represents the average peak-to-peak voltage of the signal at V_i in **Figure 5**. Record this cursor measured peak-to-peak value as V_i (pk-pk) in **Table 2** below, adjusting the

cursors as necessary for the different input frequencies. Also, for each input frequency listed in **Table 2** below, record the CH 1 **Peak-to-Peak** Waveform Measurement as V_o (pk-pk) in the table.

7. Complete **Table 2** below with measured and calculated values for each of the input frequencies listed, adjusting the frequency of the FGEN output accordingly. Be sure to include units for V_i and V_o, either by adding them to the column label or to each value. While the voltage ratio V_o/V_i is dimensionless, the dB magnitude is defined as follows: $|\mathbf{A_v}|_{dB} = 20\log_{10}(|V_o/V_i|)$. (8 points total.)

Table 2: Measured Data for the Inverting Amplifier Configuration.

Input Frequency	V_i (pk-pk)	V_o (pk-pk)	$\|\mathbf{Av}\| = \|V_o/V_i\|$	$\|\mathbf{A_v}\|_{dB}$[1]
10 Hz	0.239V	2.39V	10	20dB
100 Hz	0.243V	2.43V	10	20dB
1 kHz	0.243V	2.45V	10	20dB
10 kHz	0.239V	2.42V	10.1	20.1dB
30 kHz	0.239V	2.42V	10.1	20.1dB
100 kHz	0.235V	2.35V	10	20db
300 kHz	0.235V	1.96V	8.3	18.4dB
1 MHz	0.239V	0.971V	4.1	12.2dB

1– Voltage Gain Magnitude $|\mathbf{A_v}|_{dB} = 20\log_{10}(|V_o/V_i|)$

8. Based on your **Table 2** data, plot the magnitude in dB on the vertical axis versus frequency on the horizontal axis, using a logarithmic scale for the frequency, which is a Bode magnitude plot. The MATLAB **semilogx**() plot command can be used to provide the logarithmic frequency axis scale if you choose to use MATLAB. Include appropriate horizontal and vertical axis labels with units along with the title "Gain Magnitude versus Frequency of An Inverting Op-Amp Configuration – Your Name or Names". Replace the plot below with your version, keeping the figure number and caption. (6 points.)

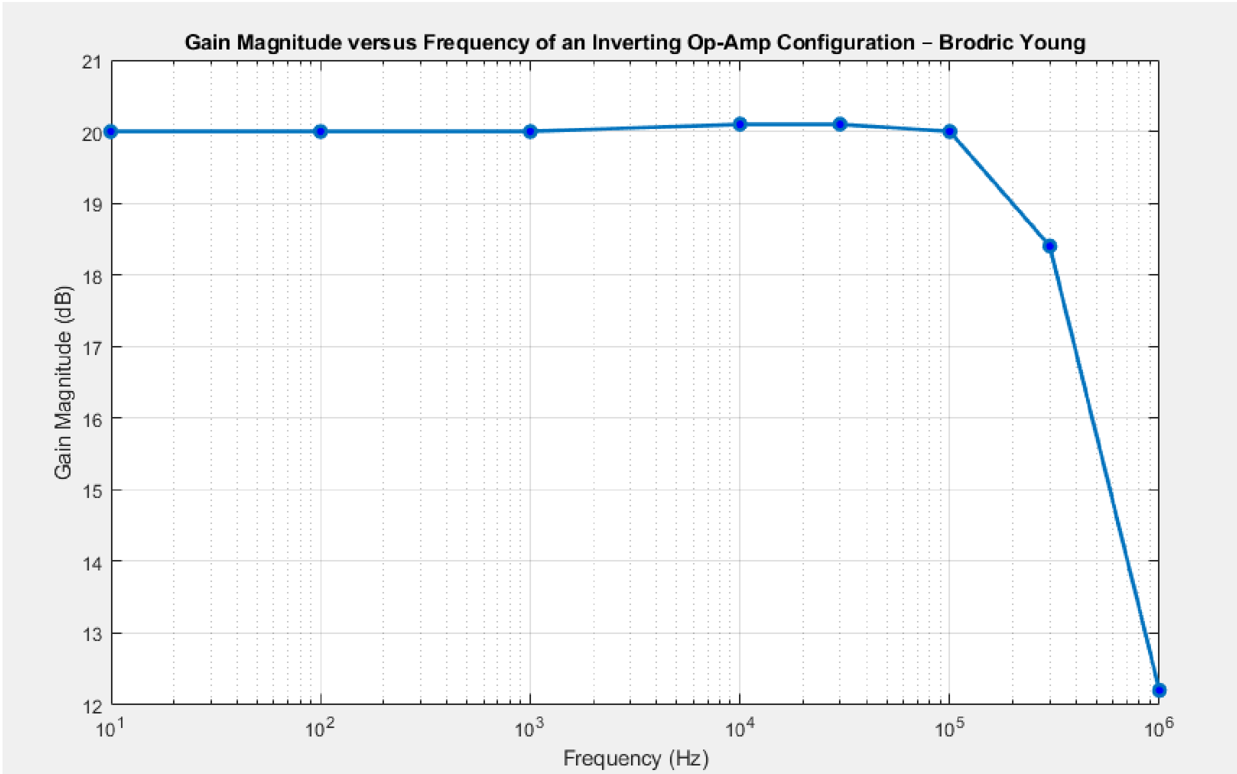
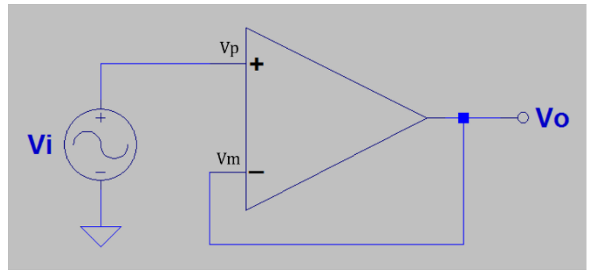


Figure 6: Frequency Response of the Inverting Op-Amp Configuration of **Figure 5**.

<u>Discussion and Conclusions Questions:</u> (For the following questions use your own words along with complete sentences. Points are to be deducted for AI generated answers.)

1. Explain how an ideal op-amp in the adjacent voltage follower configuration results in the voltage V_o to equal the voltage V_i. Include mention of open-loop gain, along with the type of feedback used. (5 points.)



For an ideal op-amp, there is no current flow into it which would make Vp and Vm equal to each other. In this case, Vp is Vi and that would mean Vm is also Vi which means Vo is also Vi since Vo and Vm are directly connected. It would have a very large open loop gain, but because there's negative feedback the gain can't get out of control because since Vo needs to equal Vi and that negative input is limiting the gain to 1.

2. Referring to **Figure 2** from Part 1, explain why the measured voltage V_O_Meas_1 was significantly less than the Thevenin voltage of 5 V, illustrated in **Figure 2**. (4 points.)

   When we connected the VMM across a and b that introduced an additional 10MΩ resistance and connected it to ground so now there was a path to ground and current could flow. So using the voltage divider we got the voltage at the positive input of the op-amp to be half of the input Thevenin voltage since it was divided between the two 10MΩ resistances.

3. Referring to **Figure 2** from Part 1, explain why the measured voltage V_O_Meas_2 was essentially equal to the Thevenin voltage of 5 V. (4 points.)

   This is because we took the additional 10MΩ resistance of the VMM out of the circuit and was no longer connected to ground but only the positive input of the op-amp. So now there's no current through the resistor and all 5V was seen at the terminal of the op-amp.

4. Calculate the ideal closed-loop voltage gain ratio, i.e., the V_o/V_i ratio not in dB, of the non-inverting amplifier circuit illustrated in **Figure 3**, including your main steps and results below. (2 Points.)

$$A_v = \frac{V_o}{V_a} = \frac{V_o}{V_o * \left(\frac{R_1}{R_1 + R_f}\right)} = \frac{R_1 + R_f}{R_1} = 1 + \frac{R_f}{R_1} = 1 + \frac{18000}{2000} = 10$$

5. Calculate the ideal closed-loop voltage gain ratio, i.e., the V_o/V_i ratio not in dB, of the inverting amplifier circuit illustrated in **Figure 5**, including your main steps and results below. (2 Points.)

$$I_{R1} = I_{Rf} \rightarrow \frac{V_i}{R_1} = \frac{-V_o}{R_f}$$

$$A_v = \frac{V_o}{V_i} = \frac{R_f}{R_1} = \frac{10000}{1000} = 10$$

6. Given the choice between the inverting or noninverting amplifier configurations used in this lab, using your own words and complete sentences explain which you would choose for an application requiring very high input impedance. (3 Points.)

    The noninverting amplifier would be better for high input impedance because the input is seen right at the positive terminal which basically ignores R3 since there's no current into the op-amp and the impedance would be very high. The inverting amplifier has a lower input impedance because it's not connected straight to the op-amp and the impedance would just be R1 and Rf which is not nearly as much as the impedance in the op-amp.

__Op-Amp Gain Lab Grading Rubric:__ **Submit an electronic version of a lab report to receive credit for doing this lab.** The goal of your **lab report is to provide sufficient documentation so that the lab can be repeated if necessary**. Therefore, simply add to this document to arrive at your lab report, as all the explanatory text, procedures, and Discussion and Conclusion questions contained in this document are required for a complete lab report. So, for your lab report, **add a cover page that includes name or names, class and name of the lab. Also add in your results, and answers to the Discussion and Conclusions questions to the existing lab document.** While you are to share all **Procedure** items with your lab partner if you worked in a pair, your **Discussion and Conclusions** section is to be uniquely yours and not a copy of your lab partners.

Lab Report Item	Points
Cover Page	2
Reasonable V_{ab}_Meas, V_O_Meas_1, and V_O_Meas_2 Values. (6 points total. -0.25 points for each missing unit.)	6
Reasonable **Table 1** data, including units for V_i and V_o. (8 points total. 0.25 points per entry, -0.1 points for each incorrect or missing unit. Units appearing at the top of column headings are fine.)	8
Figure 4. (6 points total. 2 points for using a logarithmic frequency axis, 1 point for using dB magnitude data from **Table 1**, 1 point for x-axis label including units, 1 point for y-axis label including units, 1 point for title including name or names.)	6
Reasonable **Table 2** data, including units for V_i and V_o. (8 points total. 0.25 points per entry, -0.1 points for each incorrect or missing unit. Units appearing at the top of column headings are fine.)	8
Figure 6. (6 points total. 2 points for using a logarithmic frequency axis, 1 point for using dB magnitude data from **Table 1**, 1 point for x-axis label including units, 1 point for y-axis label including units, 1 point for title including name or names.)	6
Discussion and Conclusions	20
Grammar and Professionalism	4
Total	60

Please give feedback on errors you find in this document.